

NAVAL POSTGRADUATE SCHOOL

Monterey, California



DEVELOPMENT OF A REAL-TIME HYBRID
COMPUTER SIMULATION FOR THE 3K-SES,
5 DOF, DATA-BASED PROGRAM
PART I-FAMILIARIZATION AND PLANNING

Alex Gerba, Jr. and George J. Thaler

July 1979

Progress Report Period Ending
June 1979

Approved for public release; distribution unlimited.
Prepared for:
Naval Sea Systems Command (PMS-304)
Surface Effect Ship Project Office
P.O. Box 34401
Bethesda, Maryland 20034

FEDDOCS
D 208.14/2:
NPS-62-79-008

DUDLEY KNOX LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CA 93943-5101

NAVAL POSTGRADUATE SCHOOL
Monterey, California

Rear Admiral T. F. Dedman
Superintendent

Jack R. Borsting
Provost

The work reported herein was supported by funds provided by the Naval Sea Systems Command, Surface Effects Project Office. Reproduction of all or part of this report is authorized.

This report was prepared by:

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NPS62-79-008	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Development of a Real-time, Hybrid Computer Simulation for the 3K-SES, 5 DOF, Data-Based Program. Part I-Familiarization and Planning		5. TYPE OF REPORT & PERIOD COVERED Progress Report for Period Ending June 1979
7. AUTHOR(s) Alex Gerba, Jr. and George J. Thaler		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Code 62 Monterey, California 93940		8. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Sea Systems Command (PMS-304) Surface Effect Ship Project Office P.O. Box 34401; Bethesda, MD 20034		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS N0002479WR9G196
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE July 1979
		13. NUMBER OF PAGES
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Surface Effect Ship Simulation Model Hybrid Simulation Digital Simulation		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Three degree of freedom approximate models have been developed for the XR-3 and the 3K-SES. Implementation in the IBM 360/67 and comparisons of turning characteristics with the 6 DOF program for the XR-3 and the 5 DOF program for the 3K-SES show good correlation. Hybrid implementation of the 3 DOF model of the XR-3 also shows good correlation. Hybrid implementation of the 3 DOF model for the 3K-SES is in progress, and extension to 5 DOF is being planned.		

SUMMARY

The first step in the development of a hybrid computer simulation of the data-based, 5 DOF, 3K-SES program that will operate in real-time has been completed. A 3 DOF (Flat) turn model for an approximate and simplified XR-3 craft was used to provide the equations of motion in order to become familiar with 1) the turning characteristics of the CABSES, 2) the requirements of the (NPS) NAV PG School hybrid computer with regard to signal conversion, timing, accuracy and loop delay due to both signal conversion and (right-hand-side) computation and 3) the approximate size of program that can be computed on the existing hardware of the NPS facility.

In parallel with this investigation, the 5 DOF data-based digital program for the 3K-SES has been converted from CDC to IBM FORTRAN and is now operational and will serve as the standard for evaluation of the final hybrid simulation for the 3K-SES.

Results of the hybrid computer simulation of the 3 DOF turn model of the XR-3 indicate that the installation of the 5 DOF program of the 3K-SES should proceed (in the next phase) as a straight forward application of the right-hand-side computations within the digital computer and additional degrees of freedom on the analog computer. The successful operation of the hybrid computer simulation will

depend upon ability of the 10 year-old hardware--in particular the digital computer--to compute the many computational operations required for the right-hand-side of the equations of motion in the time frame necessary to approximate real-time manual control.

TABLE OF CONTENTS

- I. Introduction
- II. Familiarization and Planning
 - A. The 3 Degree of Freedom Model
 - 1. Introduction
 - 2. Equations of Motion of the 3 DOF Model
 - 3. Identification of Craft Parameters
 - 4. Digital Simulation of the Simplified XR-3 Equations in 3 Degrees of Freedom
 - 5. Hybrid Simulation of the 3 Degree of Freedom Model of the XR-3
 - 6. Status of the 3 DOF Model Studies
 - B. The 5 Degree of Freedom Model
 - 1. Introduction
 - 2. The Digital Simulation of the 3K-SES in 5 Degrees of Freedom
 - 3. Hybrid Simulation of the 3K-SES
 - 4. Status
- III. Summary and Conclusions
- IV. References
 - Appendix A Hybrid Computer Program for the 3 DOF (Flat) Turn Equations
 - Appendix B Installation of the 3K-SES, 5 DOF Program in the IBM 360-67 Computer

I N T R O D U C T I O N

Reference 1 presents the Rohr Marine, Inc. analysis of the stability and maneuverability of the 3K-SES under direct manual control. The recommendations contained in Reference 1 included a suggestion to continue the investigation of manual control using a more realistic model of the response of the human operator to emergency conditions.

If a real time simulation can be developed it can provide a means of inserting an actual human operator in the loop, as well as any selected model of the operator. A hybrid realization of such a real time simulator appears to be feasible and would provide a convenient hands-on facility for a variety of human operator studies, plus many other studies in control and guidance.

This report presents the results of the first phase of a feasibility study, in which it is planned to develop a real time simulation using the NPS Hybrid Computer which consists of a CI-5000 analog unit and an XDS-9300 digital unit. The initial studies reported here are concerned with development of 3 DOF models for the XR-3 and the 3K, as a preliminary to the development of a 5 DOF Hybrid model.

II. FAMILIARIZATION AND PLANNING

IIA. THE 3 DEGREE OF FREEDOM MODEL

1. INTRODUCTION

The development of any computer model requires familiarity with both the system equations and the computer to be used. In addition, one needs quantitative data to insert the model into the computer, and one also needs typical performance data such as experimental test results in order to validate and verify the model. To develop a hybrid model of the 3K-SES, we chose to start by modelling the XR-3, because we have the required quantitative data, we have a good 6 DOF digital program, and we have good experimental data, plus availability of the XR-3 craft for test as needed. We also decided to start with a 3 DOF model, for several reasons:

- a) It is the simplest model which will permit turning tests that are verifiable.
- b) The complexity of the initial model will thus be minimal, but we can readily add two more degrees of freedom with confidence in the resulting 5 DOF model, because the similarity of the differential equations will permit ready application of the techniques we develop in perfecting the 3 DOF model.

In addition to this decision to start with a 3 DOF model, we chose to simplify the model by simplifying the right-hand-side of the equations. Since the terms on the right-hand-

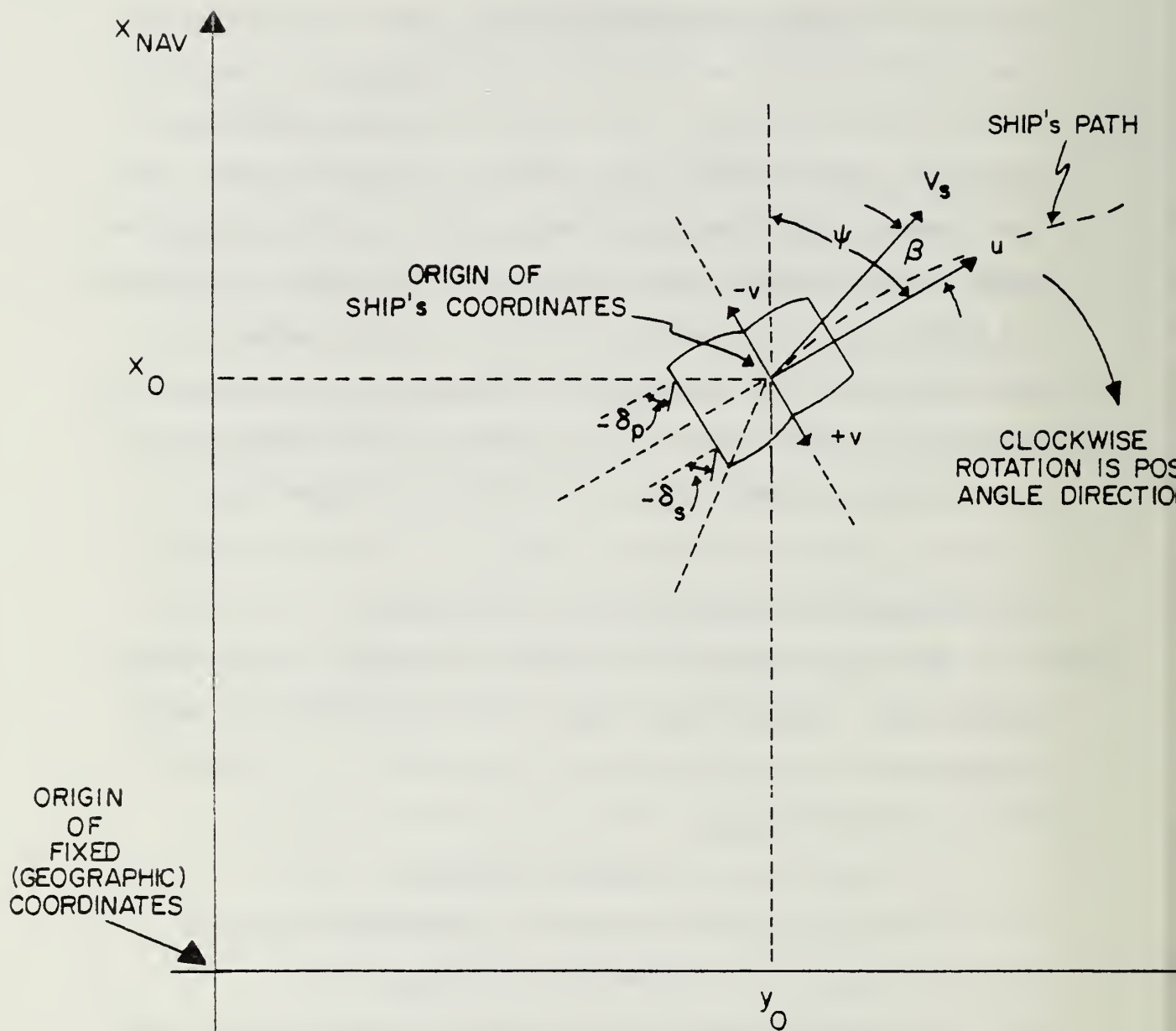
side are arithmetic calculations to be done in the digital unit, and because the many terms are additive, truncation of the right-hand-side, with simplification of the terms retained, should have little effect on results except some decrease in quantitative accuracy. This permits us to work with a less complex model in the initial stages, and addition of terms at a later point should be a simple matter. It will also have the advantage of permitting us to assess the effects of adding terms on the computational delays and on the limits of capability of our hybrid installation.

2. EQUATIONS OF MOTION OF THE 3 DOF MODEL

The three degrees of freedom to be used in this development are: SURGE, SWAY, YAW. As a result the following assumptions and approximations are needed:

1. Roll is zero
2. Pitch and draft remain constant
3. The origin of the ship's coordinate system is located at the center of gravity.
4. At $t = 0$ the ship coordinate system and the fixed (geographical) coordinate system have the same origin and the same coordinate axes.
5. At $t = 0$ the ship is heading in the positive X_{nav} direction.

Figure 1. DEFINITION OF COORDINATE SYSTEMS.



NOTE : RUDDER CONDITION FOR RIGHT TURN IS SHOWN.
ALL RUNS START AT GEOGRAPHIC ORIGIN, i.e.,
SHIP'S COORDINATE ORIGIN IS LOCATED AT
GEOGRAPHIC COORDINATE ORIGIN AT $\tau = 0.0$.

The equations of motion can then be approximated by:

$$\underline{\text{SURGE}} \quad m(\dot{u} - vr) = X \quad (1)$$

$$\underline{\text{SWAY}} \quad m(\dot{v} + ur) = Y \quad (2)$$

$$\underline{\text{YAW}} \quad I_z \dot{r} = N \quad (3)$$

Navigation

$$\dot{x}_O = u \cos \psi - v \sin \psi \quad (4)$$

$$\dot{y}_O = u \sin \psi + v \cos \psi \quad (5)$$

$$v_s = \sqrt{u^2 + v^2} \quad (6)$$

$$\beta = \tan^{-1} \left(\frac{-v}{u} \right) \quad (7)$$

In the above equations:

m = mass of the rigid ship

I_z = moment of inertia about the z-axis

$u = v_s \cos \beta$ = velocity in the x-direction (SURGE)

$v = v_s \sin \beta$ = velocity in the y-direction (SWAY)

$r = \dot{\psi}$ = angular velocity about the z-axis

ψ = heading (yaw) angle (see Fig. 1)

β = drift angle (see Fig. 1)

δ = rudder angle, $+\delta$ produces a left turn (see Fig. 1)

Also:

$$x_O = \int \dot{x}_O dt \quad u = \int \dot{u} dt \quad r = \int \dot{r} dt$$

$$y_O = \int \dot{y}_O dt \quad v = \int \dot{v} dt \quad \psi = \int \dot{\psi} dt$$

The right-hand-sides (RHS) of the equations of motion have been designated X, Y, N. These symbols represent summations of forces (X,Y) and moments (N), and each summation may consist of many terms. For the initial simplified model we have discarded all terms in the summations except the few that are obviously major contributions. The terms retained are considered sufficient to produce a working simulation which should provide qualitative agreement with reference data. At a later point the model may be refined by adding terms and adjusting terms and adjusting coefficients.

After reduction of the right-hand-sides, these force summations become:

$$X = GT \cos \delta - C_{DX} u^2 \quad (8)$$

$$Y = GT \sin \delta - C_{Dy} v |v| \quad (9)$$

$$N = -(GT \sin \delta) l_o + C_{Dy} v |v| l_w \quad (10)$$

where: (see Fig. 2 also)

GT is the gross thrust in pounds

$\delta = \delta_s = \delta_p$ = angle of all thrust vectors

C_{DX} = coefficient of drag in the direction of surge

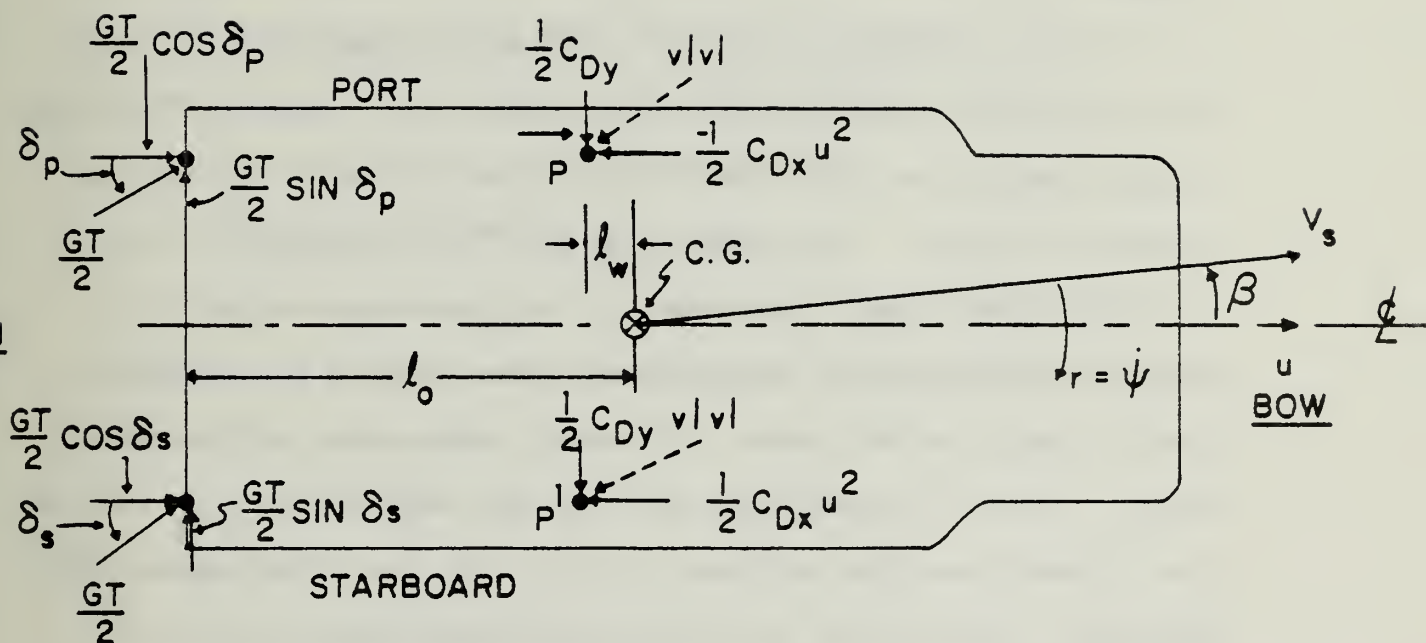
C_{Dy} = coefficient of drag in the direction sway

l_o (see Fig. 2) = thrust lever arm

l_w (see Fig. 2) = sway-drag lever arm

In further explanation of equations 8, 9, 10, note that we have chosen to model the drag forces as lumped parameters acting at two points P and P' (see Fig. 2).

ERN



NOTE: $\delta_s = \delta_p = \delta$

P - P' ARE EQUIVALENT FORCE CENTROIDS

Figure 2. FORCES ACTING FOR A RIGHT TURN.

The length l_o is the distance from the stern to the center of gravity, and l_w is the component distance (in the x-direction) from the center of gravity to the points P-P'. l_o is a fixed parameter for our initial studies (it could be changed by ship loading) but l_w is an adjustable distance which we will use as a parameter to make the model fit test data.

The coefficient C_{DX} is a lumped parameter equivalent for the skin friction effect (slender body theory). The term $C_{DX}u^2$ models the hull drag, aerodynamic effects and hydrodynamic effects. The bubble drag is not included in the initial model (will be added later) because our initial efforts are aimed at evaluation of our hybrid structure, and a simple model above critical speed will suffice for this. In like manner, in eqn. 9, the coefficient C_{Dy} models the cross flow drag effects. Note that the added mass effect has been temporarily omitted since its effect is also of second order.

Substituting equations 8, 9, 10 into equations 1, 2, 3 provides the basic equations of motion for the 3 degree of freedom model:

$$\dot{u} = \frac{1}{m} (GT \cos \delta - C_{DX}u^2) + vr \quad (11)$$

$$\dot{v} = \frac{1}{m} (GT \sin \delta - C_{Dy}v|v|) - ur \quad (12)$$

$$\dot{r} = \frac{1}{I_z} \left(-(GT \sin \delta)l_o + (C_{Dy}v|v|)l_w \right) \quad (13)$$

Equations 11, 12, 13 are applicable to any SES craft.

Selection of parameter values to be used in the equations

would depend on the particular craft, but the procedures used to identify the lumped parameter values are independent of the craft type.

3. IDENTIFICATION OF CRAFT PARAMETERS

In order to evaluate the parameters needed for the equations, the craft must be available for measurement and test (or suitable data must be available). The parameters m , I_z , l_o are constants which must be known, and GT , δ , u , v , r can be measured in steady state (if needed). Then C_{DX} , l_ω , C_{Dy} can be calculated as is shown below:

A. Surge Drag Coefficient, C_{DX}

The craft is run on a straight course with $GT =$ constant and given rudder condition δ . When steady state is reached u is measured. Then

$$\dot{u} = 0 = \frac{1}{m} (GT \cos \delta - C_{DX} u_{ss}^2) \quad (14)$$

from which

$$C_{DX} = GT \cos \delta / u_{ss}^2 \quad (15)$$

where

GT = gross thrust in pounds

u_{ss} = steady state speed in feet/sec

δ = rudder angle

B. Sway Drag Moment Arm, l_ω

Let $GT =$ constant and $\delta = \delta_1$, a fixed angle. When the craft reaches steady state in the turn the sway equation becomes

$$\dot{v} = 0 = \frac{1}{m} (GT \sin \delta - C_{Dy} v |v|) - ur \quad (16)$$

from which

$$C_{Dy} v^2 = GT \sin \delta - m u r \quad (17)$$

The steady state yaw moment equation becomes

$$\dot{r} = 0 = \frac{1}{I_z} \left[-(GT \sin \delta) l_o + (C_{Dy} v |v|) l_\omega \right] \quad (18)$$

from which

$$C_{Dy} v^2 = (GT \sin \delta) (l_o / l_\omega) \quad (19)$$

Combining equations 17 and 19:

$$r = \frac{GT \sin \delta (1 - l_o / l_\omega)}{mu} \quad (20)$$

or if we wish

$$l_\omega = l_o \frac{GT \sin \delta}{GT \sin \delta - m u r} \quad (21)$$

From Fig. 2 and eqn. 20 it is clear that the turning rate, r , is a function of the distance l_ω , with all other parameter values fixed. Since it is customary to command a turning rate, if we choose r we can then evaluate l_ω . For the XR-3, using steady state data obtained with our 6 DOF simulation,

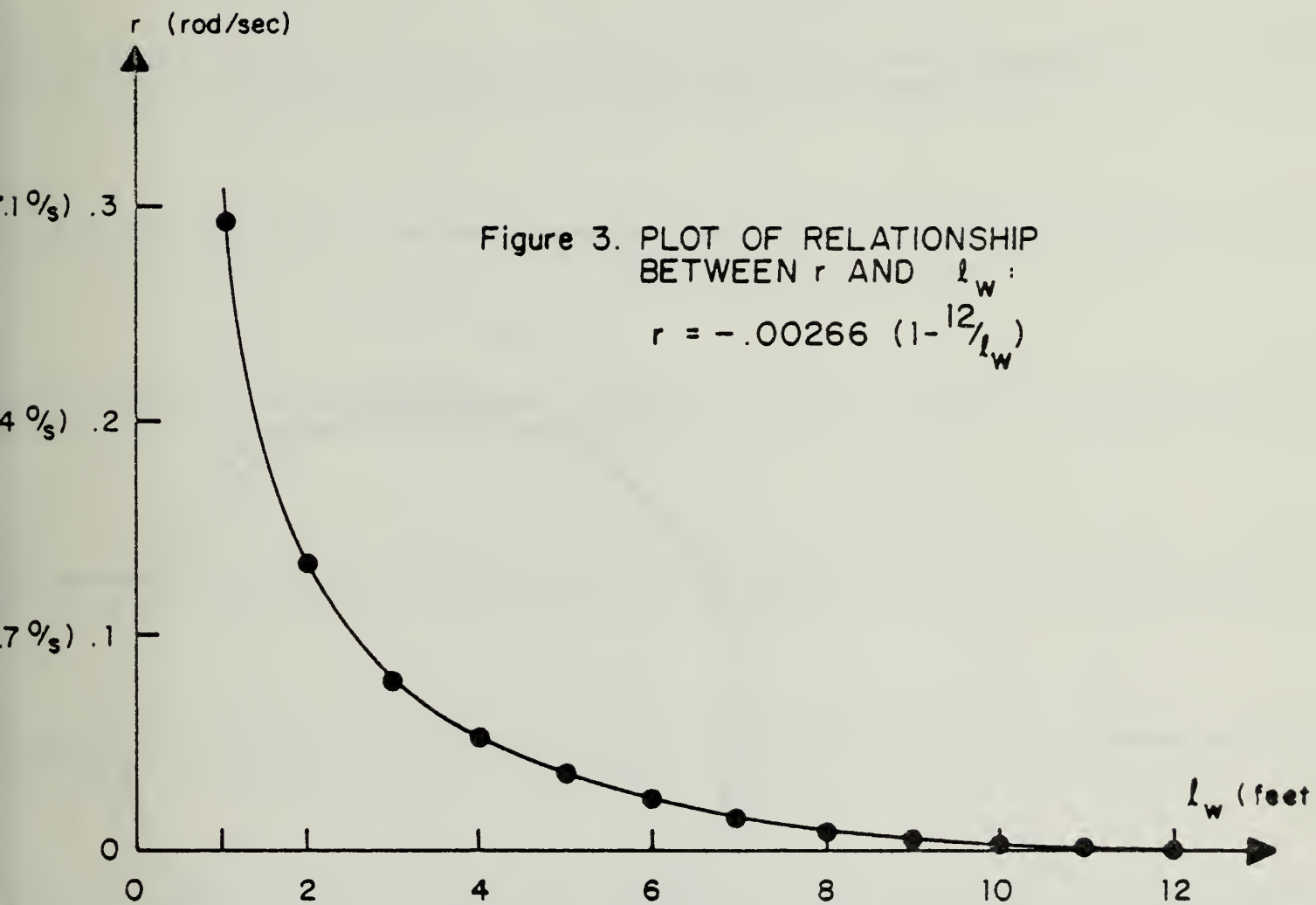
$$r = -0.0266 (1 - l_o^2 / l_\omega^2) \text{ radians/sec} \quad (22)$$

A plot of this relationship is shown on Fig. 3.

C. Sway Drag Coefficient, C_{Dy}

Again assuming steady state conditions with fixed thrust and fixed rudder, the sway equation, eqn. 17, provides:

$$C_{Dy} = \frac{-m u r + GT \sin \delta}{v^2} \quad (23)$$



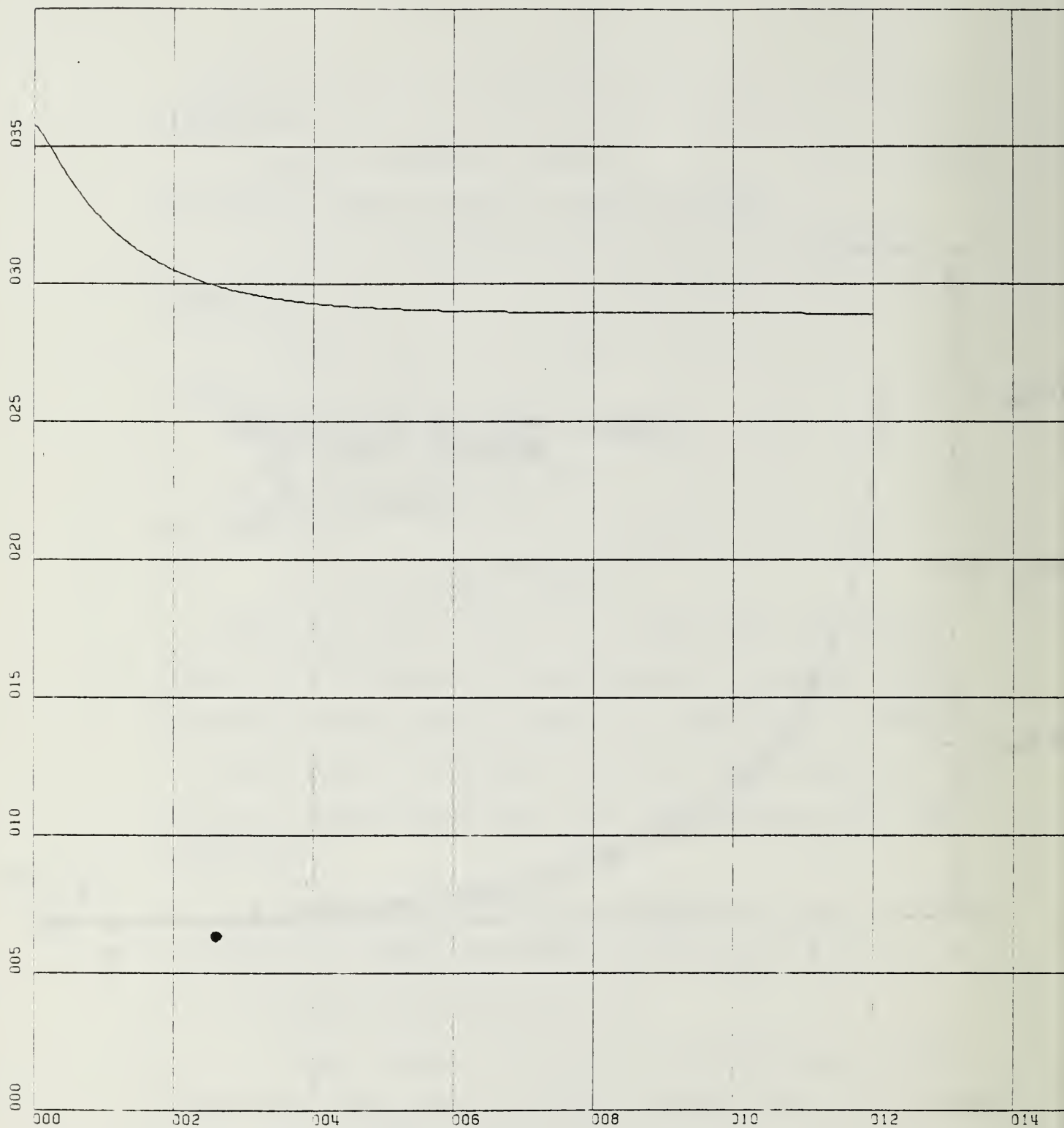


Figure 4-A. FLAT TURN DYNAMICS OF THE XR-3, PLOT
OF VELOCITY vs. TIME.
 $r = .33 \text{ RAD/SEC}$ ($l_w = 1 \text{ ft}$)

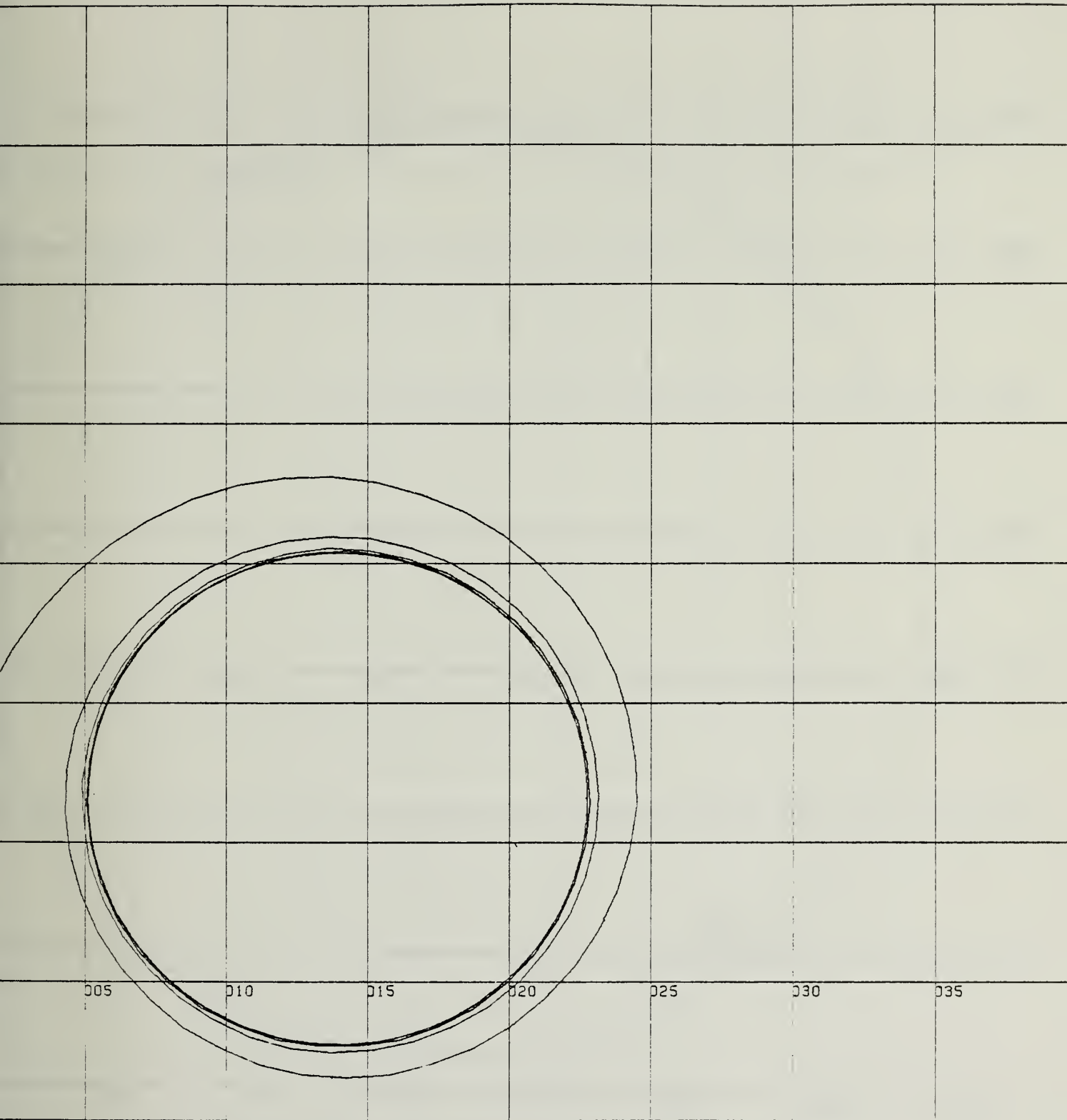


Figure 4-B FLAT TURN DYNAMICS OF THE XR-3, PLOT
OF X vs. Y.
 $r = .33 \text{ RAD/SEC}$ ($l_w = 1 \text{ ft}$)

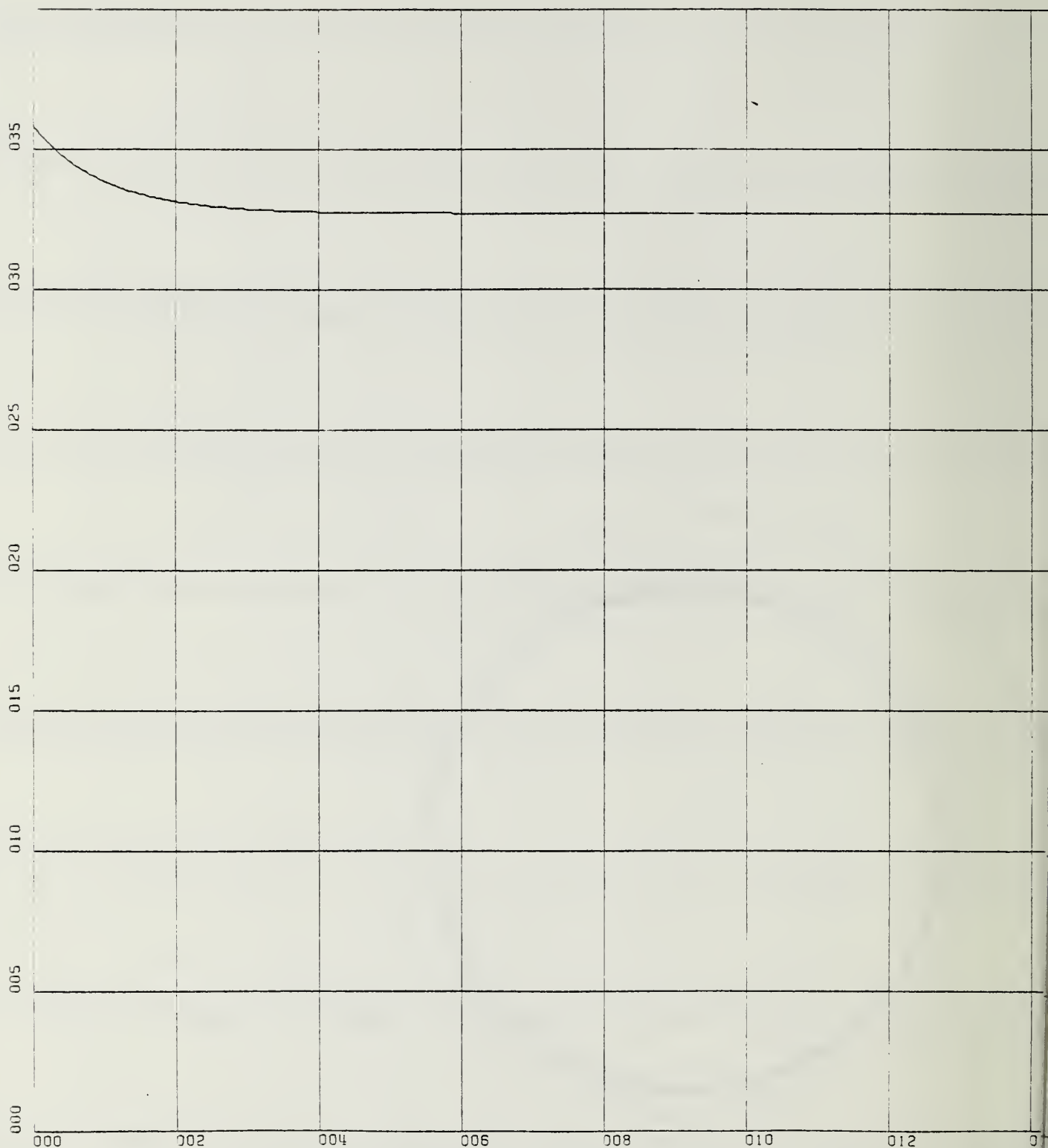


Figure 5-A. FLAT TURN DYNAMICS OF THE XR-3, PLOT
OF VELOCITY vs. TIME.
 $r = 0.1 \text{ RAD/SEC}$ ($l_w = 2.5 \text{ ft}$)

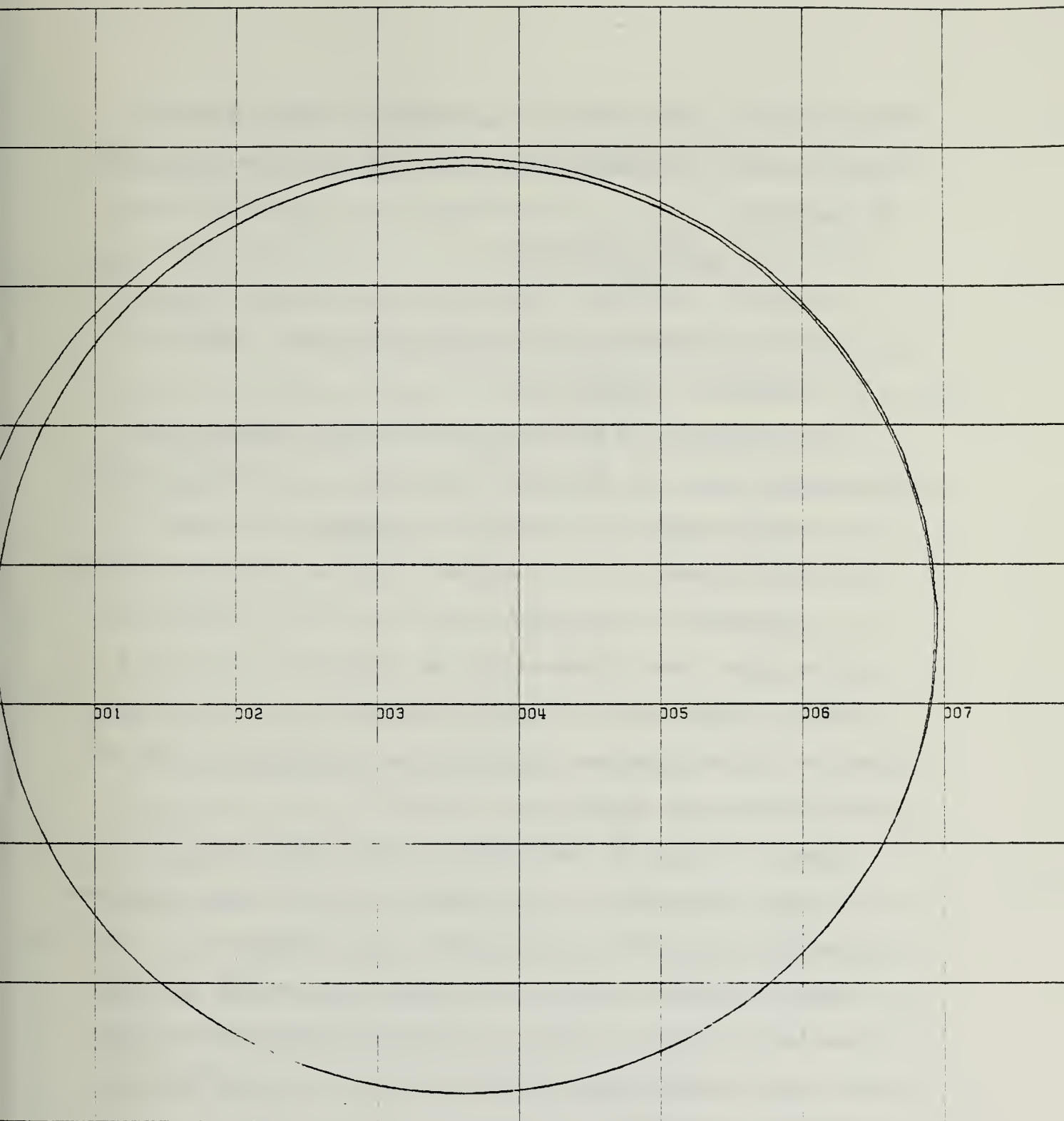


Figure 5-B FLAT TURN DYNAMICS OF THE XR-3, PLOT
OF X vs. Y.
 $r = 0.1 \text{ RAD/SEC}$ ($l_w = 2.5 \text{ ft}$)

For a given turning rate, r , we know all values except v , which can be calculated using the surge equation, eqn. 11, to provide:

$$v = \frac{C_{DX} u^2 - GT \cos \delta}{m r} \quad (24)$$

4. DIGITAL SIMULATION OF THE SIMPLIFIED XR-3 EQUATIONS IN 3 DEGREES OF FREEDOM

The equations of motions as previously derived were programmed into the IBM 360/67 computer. A fixed step size was used to verify the program and validate the model. Using a turn rate, $r = .33$ rad/sec, and an integration step of 0.1 seconds the simulation was run for 120 seconds of problem time, then repeated for an integration step of 0.01 seconds. Comparison of results showed that an integration step of 0.1 seconds was suitable, all variables in the two runs agreeing to within 1%.

Figure 4A and 4B show plots of u vs time and x vs y for a flat turn with $r = .33$ rad/sec ($l_w = 1$ ft.). Figures 5A and 5B show similar plots for $r = 0.1$ rad/sec ($l_w = 2.5$ ft.). A number of additional runs were made but results are not given here. Based on these runs we feel that the program has been satisfactorily verified, i.e., it is solving the equations correctly.

The following observations seem appropriate:

1. Eqn. 22 and Fig. 3 are at least qualitatively correct.
2. The effect of added mass is negligible.

3. We have gained confidence that, given the measured performance of any SES in an approximate flat turn, and given values for the parameters GT , δ , u , r , m and l_o , we can determine a value of l_w which provides a simulation matching the measured performance reasonably closely.

4. If the simulation is performed with an initial step in the thrust angle, δ , approximate values for the system time constants can be evaluated from the resulting data.

For the XR-3 operating in a flat turn the time constants are:

Variable	Time Constant
u	11.0 sec
v	0.8 sec
r	1.2 sec
β	0.9 sec

To validate the 3 DOF model, additional runs were made using the digital 6 DOF Oceanics program as modified by our NPS group for the XR-3. Also the 3 DOF model was run with 3K-SES data, and the 5 DOF model of the 3K-SES was run. For the XR-3 tests a step of rudder of 0.5 radians was suddenly applied with craft speed at 20 knots. For the 3K-SES tests and 11° rudder was applied by ramping up for 1.0 second and holding at the 11° value. Craft speed was 60 knots. Comparison of the 3 DOF, 6 DOF and 3 DOF Hybrid runs for the XR-3 is shown on Fig. 6. Correlation is not as bad as appears by inspection. Turning diameter and time for a 360° turn are almost identical. We presently attribute the differences to the fact that the 3 DOF model does not include

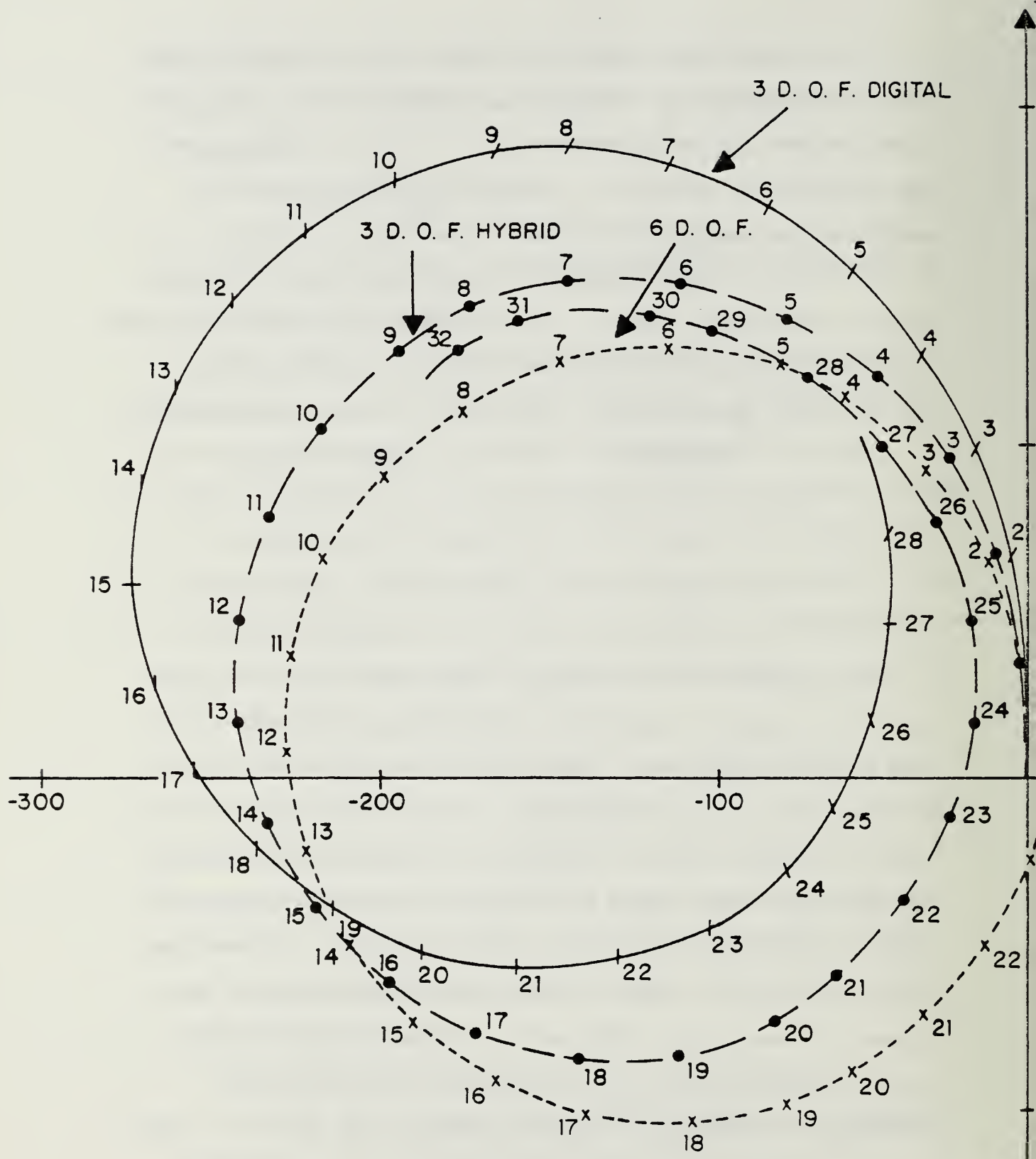


Figure 6. TURNING CHARACTERISTICS OF THE XR-3 RESPONSE TO LEFT RUDDER, 0.5 RADIAN STEP, 20 KNOTS.

a term for bubble drag.

Figure 7 compares the 3 DOF run with the 5 DOF run for the 3K-SES. The results are almost identical, despite simplifications in the 3 DOF. This gives confidence that our modelling technique will work well when we hybridize.

5. HYBRID SIMULATION OF THE 3 DEGREE OF FREEDOM MODEL OF THE XR-3

In developing a hybrid model various arrangements and structures (programming) are possible. The philosophy chosen for our initial hybrid model is shown in the block-flow diagram of Fig. 8. Details of the programming are given in Appendix A for the simplified XR-3 model.

The simplified XR-3 model was installed in the hybrid system and tested. Comparison of results with those obtained by digital simulation showed almost identical performance, differences being less than 2%.

In developing the hybrid simulation a major concern has been the amount of time delay introduced into the loop by the A/D and D/A conversions and by the time required to perform the digital computations. We have monitored these delays in the 3 DOF model with results as follows:

1. The fundamental loop delay using D/A for \dot{u} , \dot{v} , \dot{r} , x , y and A/D for u , v , r was 33 ms.
2. A lower language subroutine exists, called ADDA, which can be used to replace the Fortran subroutines for A/D and D/A. This can reduce the delay by 25%.

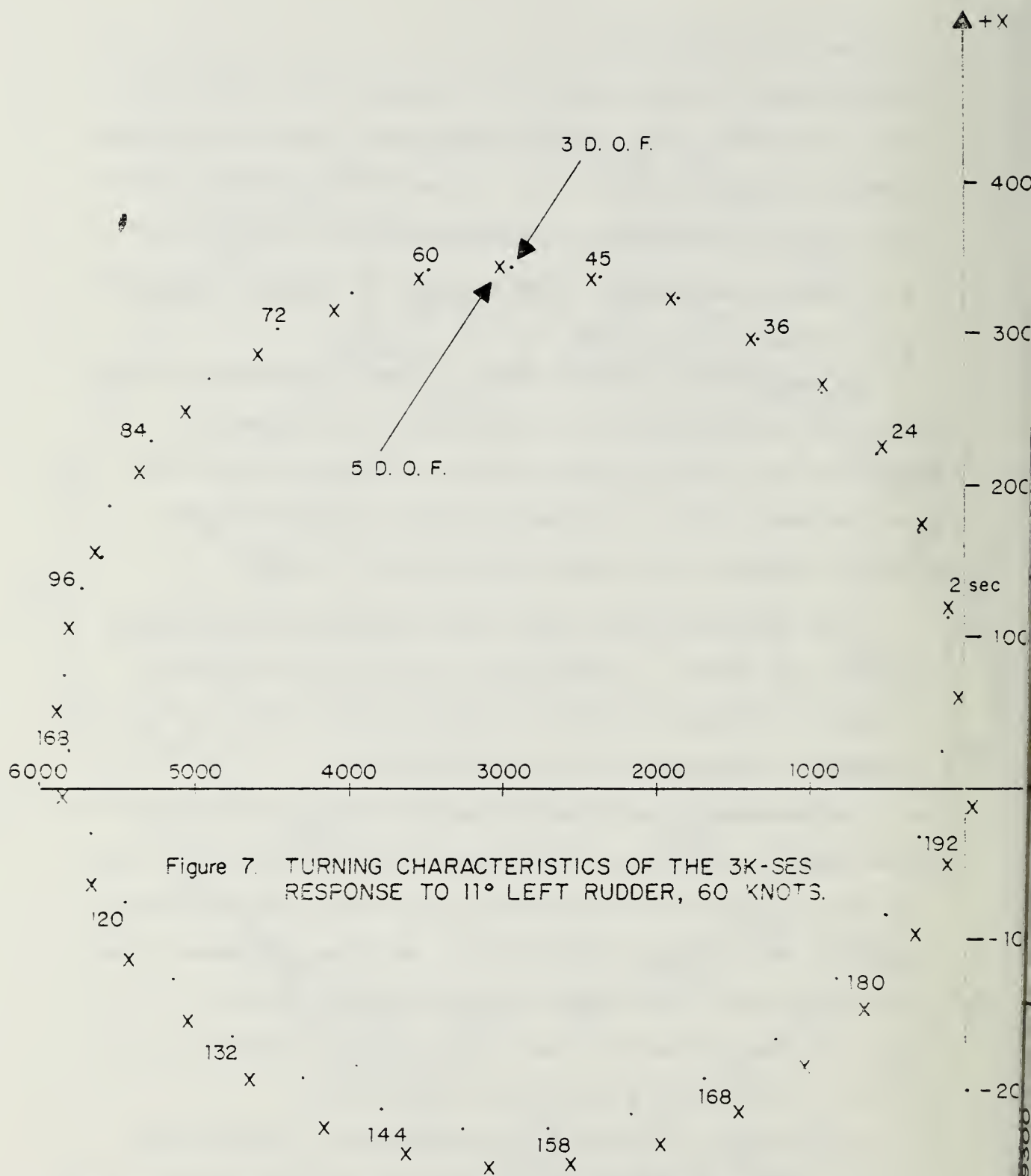


Figure 7. TURNING CHARACTERISTICS OF THE 3K-SES RESPONSE TO 11° LEFT RUDDER, 60 KNOTS.

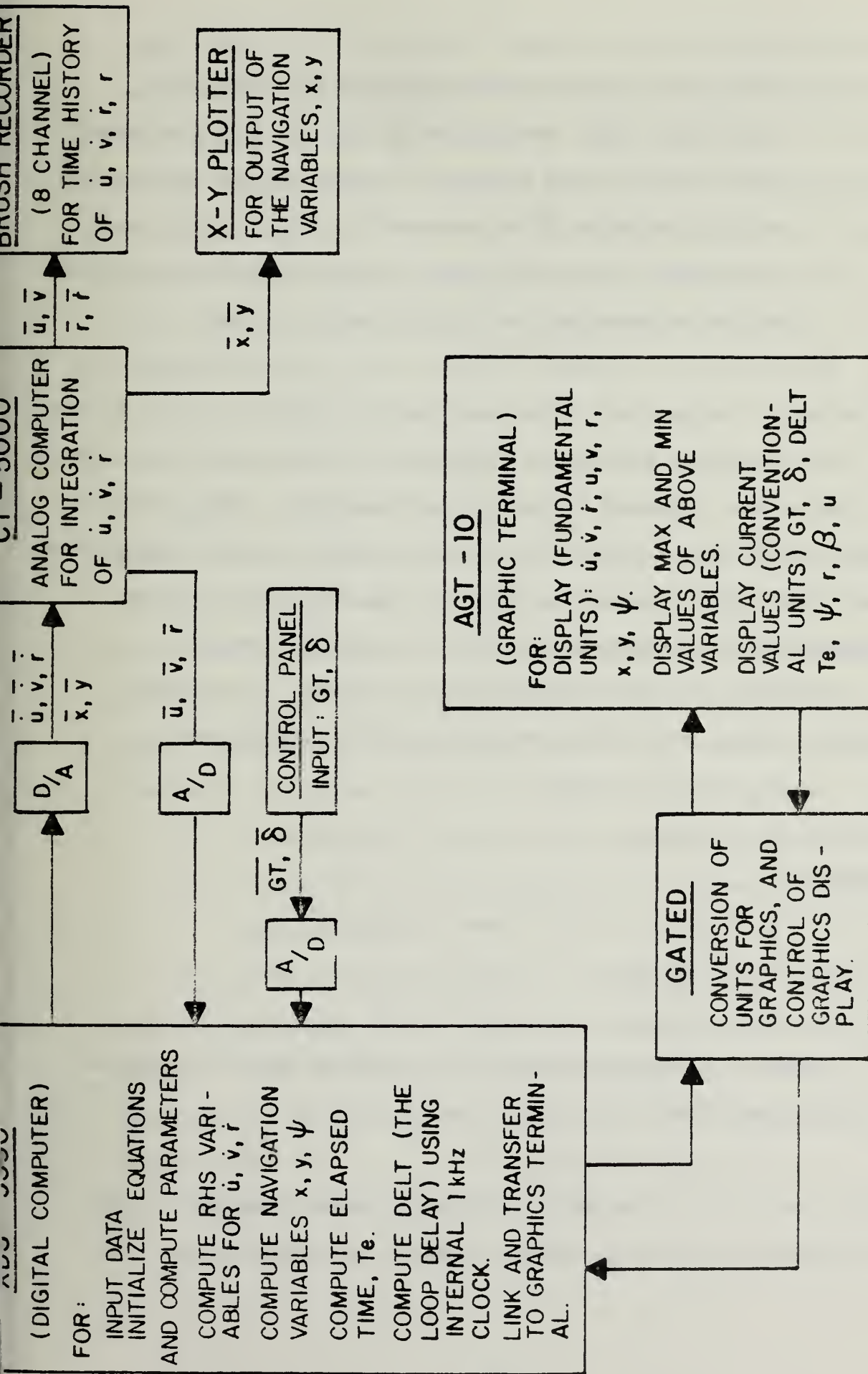


Figure 8. STRUCTURE FOR HYBRID SIMULATION OF 3 D.O.F. (FLAT) TURN EQUATIONS.

3. Additional delays are introduced by using A/D for thrust (GT) and thrust angle (δ) [76% increase] and by use of the Graphics Signal (Gated) conversion of the variables [67% increase]. Total loop transport delay using D/A, both A/D units and the Graphics signal conversion was approximately 78 ms.

We know how to reduce the loop delay substantially, but in view of the system response time this may not be necessary.

One possible source of difficulty in the hybrid simulation is the cross coupling between the equations. When operating near steady state conditions during small yaw angle maneuvers the linearized equations indicate that the roots of the characteristic equation may be very lightly damped.

Consider straight-ahead motion (thrust) at constant speed. The linear model sway and yaw equations are:

$$\dot{x}_2 = a_{22}x_2 - u_0x_3$$

$$\dot{x}_3 = a_{32}x_2$$

where

$$\underline{x} \triangleq [\Delta u, \Delta v, \Delta r]^T, \text{ and } \Delta u = 0$$

$$a_{22} = f_1(x_2)$$

$$a_{32} = f_2(x_2)$$

Combining these equations, the characteristic equation of the simplified 3 DOF model is

$$s^2 + a_{22}s + u_0a_{32} = 0$$

The locations of the roots of this equation depend on the values of a_{22} and a_{32} , both of which are functions of the

sway velocity. For small values of sway velocity the roots are complex conjugates and approach the origin of the s-plane as the sway velocity approaches zero. For larger values of sway velocity such as those encountered in a turn maneuver the roots are real and negative, providing a well damped response for yaw and sway motions. This appears to be similar to the Dutch Roll effect in aircraft.

For straight ahead runs using the digital program for the 3 DOF model and setting the initial value of v to zero, no sway-yaw motions are observed. However, if we set a small initial condition on v a transient oscillation is observed in both sway and yaw as shown on Fig. 9. This verifies the existence of the phenomenon, and we expect to encounter it in the hybrid since the equations are the same. However, in the hybrid there is a possibility that the roots may move into the right half s-plane due to either:

1. DC unbalance in the analog computer integrators, or,
2. Excessive loop delay from A/D, D/A and digital computations.

The first of these possible causes can be avoided by careful balancing of the operational amplifiers before running. The effect of the loop delays can be controlled somewhat by minimizing the number of terms requiring digital computation.

6. STATUS OF THE 3 DOF MODEL STUDIES

These appear to be both complete and successful. Both

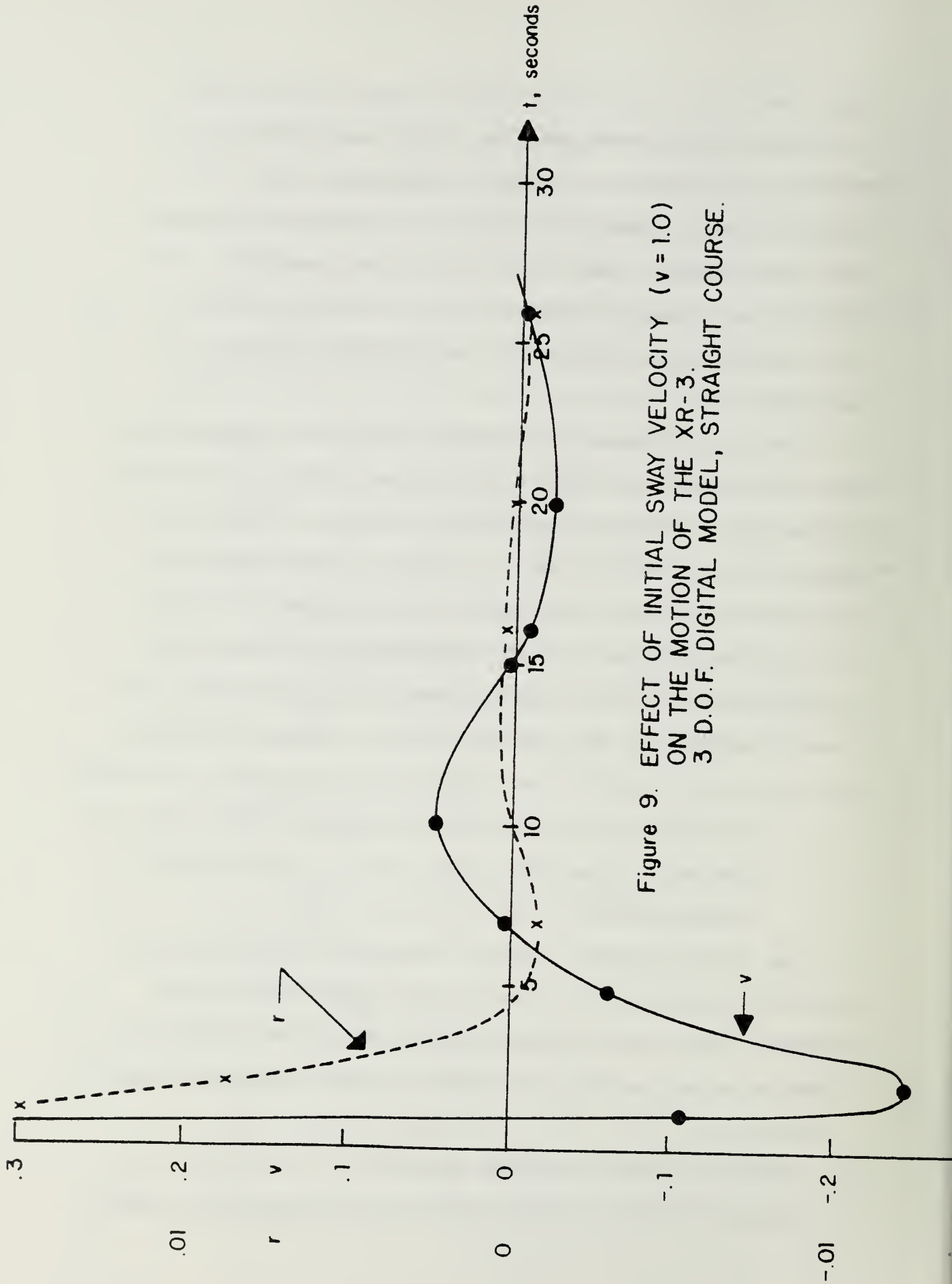


Figure 9. EFFECT OF INITIAL SWAY VELOCITY ($v = 1.0$) ON THE MOTION OF THE XR-3.
3 D.O.F. DIGITAL MODEL, STRAIGHT COURSE.

qualitative and quantitative agreement have been achieved with the 5 DOF digital simulation as a reference. Future studies will be aimed primarily at the 5 DOF model of the 3K-SES except when we wish to correlate computer data with specially designed experiments.

IIB. THE 5 DEGREE OF FREEDOM MODEL

1. INTRODUCTION

Having developed a simplified 3 DOF model of the XR-3, we now proceed to use the knowledge thus obtained and apply it to the 3K-SES. We do not plan to develop a 5 DOF hybrid model of the XR-3. Our procedure is to install the NSRDC 5 DOF program for the 3K-SES in our IBM 360/67 computer, generate reference curves with it, obtain any numbers we need for our 5 DOF hybrid simulation, then verify and validate the hybrid model of the 3K-SES.

2. THE DIGITAL SIMULATION OF THE 3K-SES IN 5 DEGREES OF FREEDOM

This program was obtained from NSRDC. It has been written for a CDC machine and had to be converted to the IBM version of Fortran for our computer. This has been completed, the program is operational and as far as we know has no obvious "bugs". We are familiarizing ourselves with the program, and exercising it to obtain data we will need in developing the 5 DOF hybrid model, and for validating it.

Details of the conversion-problems encountered, their solutions, etc. are discussed in Appendix B.

3. HYBRID SIMULATION OF THE 3K-SES

This is under development at the present time. Hopefully we need only insert a new set of constants in the

equations of the hybrid XR-3 model, but undoubtedly other adjustments and modifications will be needed, particularly in the trade-off of digital vs analog computation in order to perform a real-time simulation.

4. STATUS

Progress has been satisfactory. It is too early to predict future developments.

III. SUMMARY AND CONCLUSIONS

The NPS Hybrid Computer consisting of the XDS-9300 digital and the CI 5000 analog computers has been programmed to simulate the 3 DOF Flat Turn maneuvering dynamics of the CAB type Surface Effect Ship.

The XR-3 has been programmed with simplified modelling of the drag forces and thrust-input force on the hybrid computer for simple flat turn maneuvers. An evaluation of the hybrid simulation was carried out by comparison of the time histories of the velocities and the navigation variables against those values obtained from the 3 DOF digital simulation for the same maneuvers. In addition, the XR-3 hybrid 3 DOF results were compared to the 6 DOF loads and motion output.

The result of this comparison was that the hybrid computer simulation produced a time response to a step rudder input that produced a navigational turning plot that was in-between the all digital 3 DOF and all digital 6 DOF trajectories.

Additionally the 3 DOF simplified RHS (right-hand-side) digital program was operated for the same turning conditions that was used for the 5 DOF, DBSIM5D Program and the comparison indicates close agreement in the navigational trajectories for an 11 degree vectored thrust angle full-turn maneuver.

This feasibility study has shown that the hybrid computer implementation for the 5 DOF 3K-SES in real-time is possible with the available equipment at the NPS Computer Laboratory. Real-time computation is of course only approximated when using the hybrid computer. The loop transport delay inherent in this simulation is due to the signal conversion (A to D and D to A) and the necessary digital computation for the acceleration forces and moments. The magnitude of this delay time has a fixed minimum value as a result of signal conversion and a maximum value due to right-hand-side calculation required for the acceleration added to the fixed time due to the signal conversion. Real-time computation accuracy is determined principally by the magnitude of this maximum value for the loop delay.

The 3K-SES was approximated with the simplified 3 DOF Flat Turn equations and the results were compared. It was shown that the full maneuvering trajectories for an 11 degree thrust angle compared very closely with the 5 DOF, DBSIM5D Program results. These results indicate that only a few terms on the RHS may be all that are required to simulate the 3K-SES for the type of maneuvering control studies to be conducted in the future on the hybrid computer.

The conclusion of this feasibility study is that successful implementation of a hybrid computer, real-time simulation of the DBSIM5D Program has a very high probability. The degree of complexity necessary for the RHS

computation will be the limiting factor on the loop delay that controls the real-time accuracy.

IV. LIST OF REFERENCES

1. E.H. Price, R.C. Stoner, V.L. Wener, Stability and Maneuverability Report, CDRL No. E03L, Document No. TTP0013A, Rohr Marine, Inc., Chula Vista, CA.,
31 August 1978

APPENDIX A. HYBRID COMPUTER PROGRAM FOR THE
3 DOF (FLAT) TURN EQUATIONS

A general schematic diagram of the hybrid structure used is shown in Fig. A-1. The listing of the digital program for the XDS-9300 computer is also included in this appendix, and the analog computer connections are shown on Fig. A-2.

As may be seen from the listing of the digital program, the right-hand-sides (RHS) of the acceleration equations for the 3 DOF are computed on the XDS-9300, which also does the magnitude scaling for the analog computer (CI-500) voltages. In addition the XDS-9300 provides the required control logic, timing and temporary storage of computed variables.

The graphics terminal (AGT-10) provides real time display of the desired output and control variables, as well as their maximum and minimum values. Piloting of the craft is carried out at the graphics terminal. Additional permanent record outputs of navigation x and y are obtained with an XY-pen recorder, and plots of other system variables are obtained on an 8 channel Brush recorder.

A sample of the x-y output for the 3 DOF simplified XR-3 craft is shown on Fig. A-3. The plot starts with a right turn ($\delta = -0.5$ radians) at $t = 0$, using a terminated ramp input. The rudder was held at $\delta = -0.5$ for two turns, then reversed to $\delta = +0.5$ for a half turn, followed by

HYBRID COMPUTER

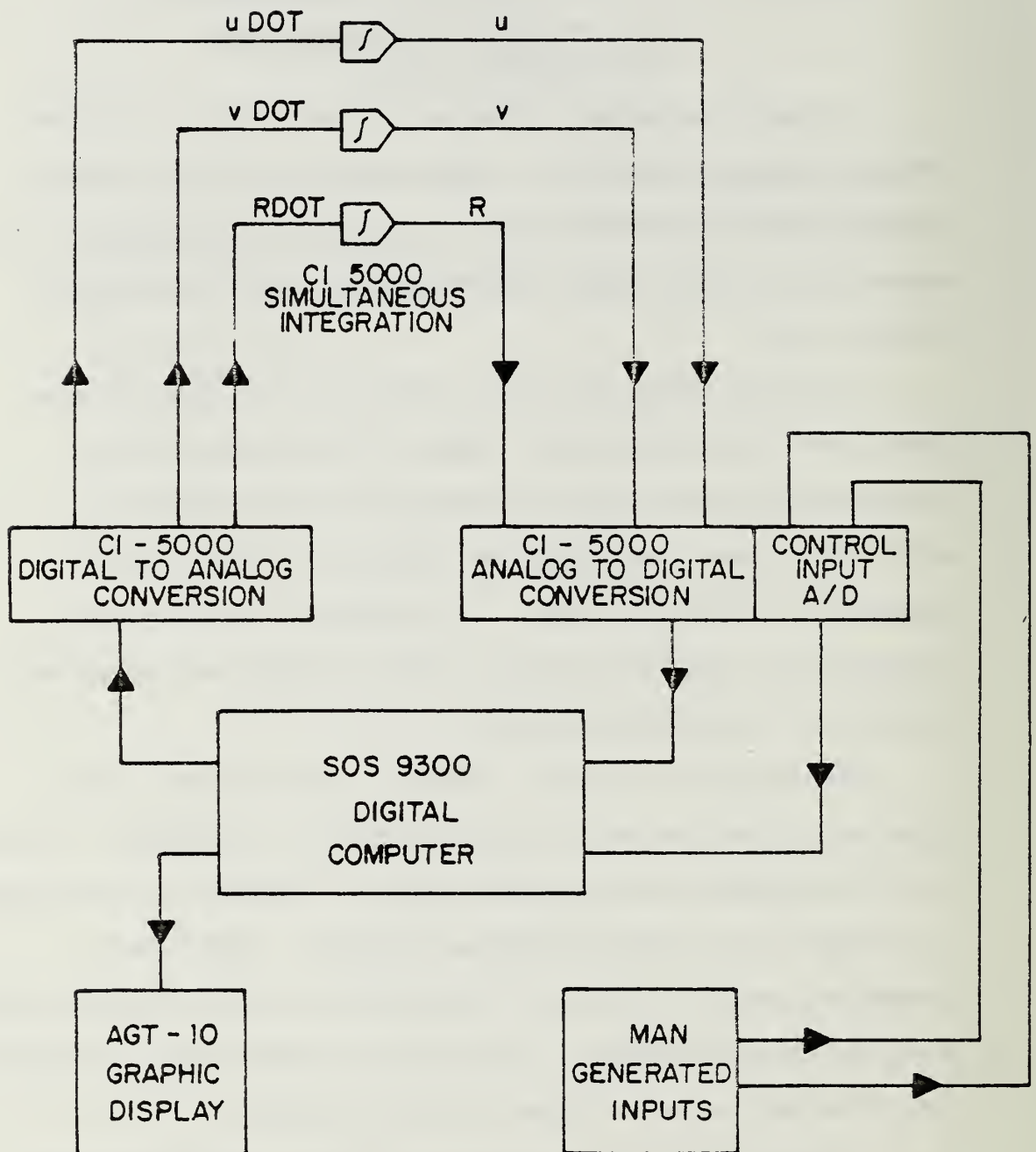


Figure A-1. BLOCK DIAGRAM OF THE HYBRID STRUCTURE.

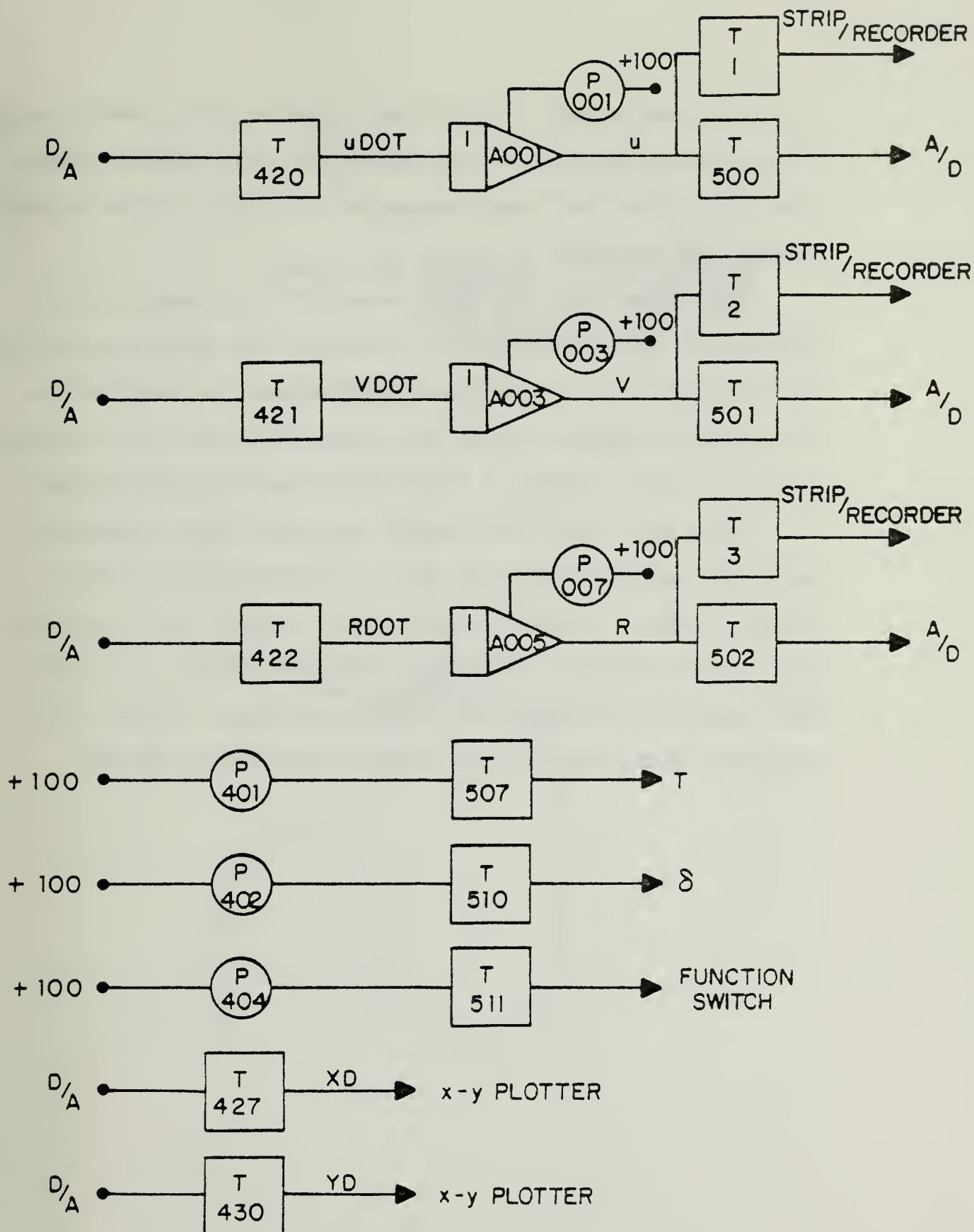


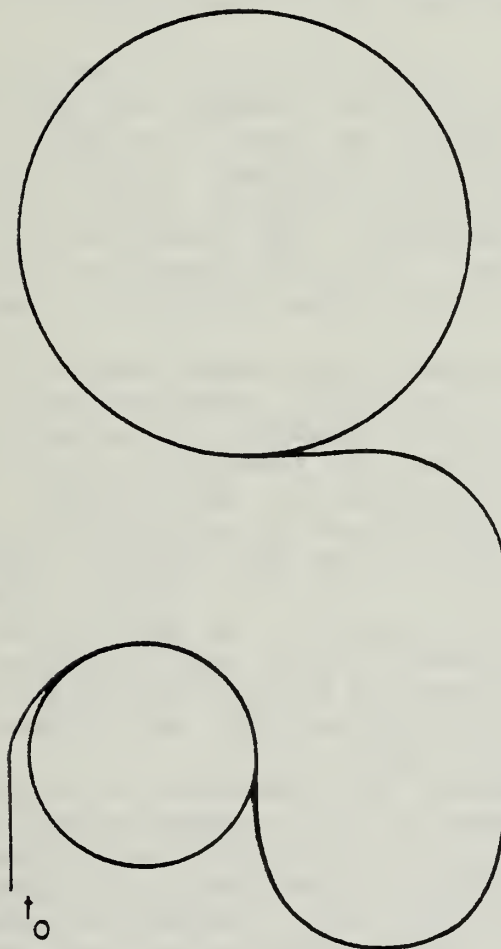
Figure A-2. DIAGRAM OF THE ANALOG COMPUTER CONNECTIONS.

$\delta = 0.0$, then again $\delta = +0.5$ for a quarter turn, and finally a right turn using $\delta = -.29$ radian for two complete turns. The total time for these maneuvers with the XR-3 was approximately $3\frac{1}{2}$ minutes.

Note that the CI-5000 is used only for analog integration of the accelerations to obtain the desired velocities for the digital computation. Displacement is computed in the digital computer using the trapezoidal rule for integration as done on the Oceanic's 6 DOF Loads and Motions Program.

Note also that the present structure and programming use only existing hardware and we consider them a feasibility study. If results show that we have been successful, then we must prepare for manual control studies, and this may require development of a more realistic "cockpit" to simulate conditions in the control room of the 3K-SES.

Figure A-3. SAMPLE OF THE HYBRID
OUTPUT x-y PLOT FOR
THE 3 D.O.F. XR-3



APPENDIX B. INSTALLATION OF THE 3K-SES, 5 DOF
PROGRAM IN THE IBM 360/67 COMPUTER

In the fall of 1978 the 3K-SES, 5 DOF data based program called DBSIM5D was delivered to the Naval Post-graduate School, at which time a commitment was made by the NPS group to attempt a hybrid computer simulation based on this program.

In the spring of 1979, DTNSRDC shipped the card deck and the output data for a typical 3K-SES run, obtained by DTNSRDC on a CDC computer. The deck was to be used in installing the program in the IBM 360/67, and the output data provided information for verification and validation. The major problem in the process of installation was the conversion from CDC Fortran to IBM Fortran. With the help of Mr. Roger Hilleary of the NPS Computer Facility, the interactive graphics terminal was used to edit the program. After some 50 man hours of effort the first successful batch run was made in April 1979.

Complete success in the conversion did not occur until a correction was added to the newly programmed TIMER, to allow for a stop at the desired stop time rather than a premature stop time due to the timer program.

To validate the IBM version of the program we duplicated the sample run for the 3K-SES. This run, as provided by DTNSRDC, was for a left turn, using an 11 degree effector angle and a speed of 60 knots. The sample run terminated after 14.5 seconds of real (problem) time. The 11 degree

effector angle was programmed as a ramp which terminated after 1 second, and remained constant at 11 degrees for an additional 50 seconds.

A comparison of the output of the IBM 360/67 version with the sample run data from the CDC computer showed that the recorded variables were in complete agreement within the accuracy differences of the two computer word length.

The problems of conversion were simple but time consuming and may be listed as follows:

1. 6 character variable name limit on the IBM computer as compared with a 7 character limit on the CDC.
2. Single statement limit on the IBM computer versus multiple statement on a single card for the CDC.
3. Identification of temporary files used for the output data.
4. Identification of the timing control and programming the IBM computer timer to provide the functions required for operation of the program.
5. Addition of the proper job control language (JCL) cards to compile, link and compute.

AFBRTRAN LS,GS

```

1:  DIMENSION ITEXT(29),ILAP(24),POTS(24),PSTK(24),IMAGE(3000)
2:  C,IL(24),TITLE(24),AD(10),AA(12),ILA1(24),ILA2(24),ILA3(24),
3:  CILA4(24),ILA5(24),ILA6(24),ILA7(24),ILA8(24),IPLST(10),IVIEWA(2
4:  CIVIEWB(20)
5:  EQUIVALENCE (AD(1),A11),(AD(2),A21),(AD(3),A31),(AA(1),B11),
6:  C(AA(2),B21),(AA(3),B31),(AA(4),B41),(AA(5),B51),(AA(6),B55),
7:  C(AA(7),B61),(AA(8),B71),(AA(9),B81),(AA(10),B91),(AA(11),B101),
8:  C(AA(12),B111),(AD(4),A41),(AD(5),A51),(AD(6),A61),
9:  C(AD(7),A71),(AD(8),A81),(AD(9),A91),(AD(10),A101)
10:  CALL DAL(.0,.0,.0,.0,.0,.0,.0,.0,.0,.0,.0,.0)
11:  CALL SETPST(4HPO01,.0,4HPO03,.0,4HPO05,.0,4HPO07,.0,4HPO11,.0,
12:  C4HPO15,.0)
13:  CALL RESET(1000)
14:  CALL COMPUTE
15:  CALL DGINIT(2,IVIEWA,20,IER)
16:  CALL DGINIT(2,CIVIEWB,20,IER)
17:  CALL DGINIT(2,IPLST,10,IER)
18:  CALL DTINIT(1,ITEXT,29,IER)
19:  ENCODE(96,1,TITLE0)
20:  1  FORMAT('          REAL TIME          ')
21:  CALL TEXTS(1,TITLE0,24,6,1,3,3,IER)
22:  ENCODE(96,2,TITLE1)
23:  2  FORMAT('          MOTION ANALYSIS PROGRAM          ')
24:  CALL TEXTS(1,TITLE1,24,9,1,3,3,IER)
25:  I=1000000
26:  CALL DELAY
27:  IVIEWB(1)=IHEAD(1,10)
28:  IVIEWB(2)=IPACK(0.0,1.0,0)
29:  IVIEWB(3)=IPACK(0.0,0.5,1)
30:  IVIEWB(4)=IPACK(-1.0,0.0,0)
31:  IVIEWB(5)=IPACK(-0.5,0.0,1)
32:  IVIEWB(6)=IPACK(0.5,0.0,0)
33:  IVIEWB(7)=IPACK(1.0,0.0,1)
34:  IVIEWB(8)=IPACK(0.75,1.0,0)
35:  IVIEWB(9)=IPACK(0.75,0.5,1)
36:  IVIEWB(10)=IPACK(0.5,0.75,0)
37:  IVIEWB(11)=IPACK(1.0,0.75,1)
38:  IVIEWB(12)=0
39:  CALL GRAPH0(2,IVIEWB,12,1,IER)
40:  IPR=0
41:  IC0A=0
42:  IC0=0
43:  NDA=12
44:  NAD=10
45:  IN=0
46:  X=-100.
47:  TIME=0.0
48:  AAAA=0.
49:  P=0.0
50:  Q=0.0
51:  RHO=2.0

```

```

G=32.2
M=130.
CDX=.3
CDY=1555.0
LW=1.0
L9=10.
J=1
IZ=3333.
A22=1.0
AU=.45
AUDBT=.45
AV=.020
AVDET=.020
AR=0.0100
ARDET=0.0100
AX0=25.
AY0=25.
AT=3.75
AZ=.005
IQG=0
TX=0.0
TY=-6000.
650 CALL DTINIT(1,ITEXT,29,IER)
501 FORMAT('PRESENT',2F10.2,'      ',F4.2,'      ',F8.2,'      ',F6.3,
C'      ',F6.3)
525 FORMAT('MAXIMUM',2F10.2,'      ',F4.2,'      ',F8.2,'      ',F6.3,
C'      ',F6.3)
526 FORMAT('MINIMUM',2F10.2,'      ',F4.2,'      ',F8.2,'      ',F6.3,
C'      ',F6.3)
507 FORMAT('PRESENT',F8.2,F10.3,'      ',F4.2,'      ',F8.3,'      ',
CF5.3,'      ',F5.3)
527 FORMAT('MAXIMUM',F8.2,F10.3,'      ',F4.2,'      ',F8.3,'      ',
CF5.3,'      ',F5.3)
528 FORMAT('MINIMUM',F8.2,F10.3,'      ',F4.2,'      ',F8.3,'      ',
CF5.3,'      ',F5.3)
511 FORMAT('PRESENT',F7.3,F10.3,'      ',F10.2,'      ',F8.3,'      ',F6.3,'
C      ',F6.3)
529 FORMAT('MAXIMUM',F7.3,F10.3,'      ',F10.2,'      ',F8.3,'      ',F6.3,'
C      ',F6.3)
530 FORMAT('MINIMUM',F7.3,F10.3,'      ',F10.2,'      ',F8.3,'      ',F6.3,'
C      ',F6.3)
516 FORMAT(F6.2,'      ',F4.2,'      ',F4.3,'      ',F6.2,'      ',F5.3,'
C      ',F7.2,'      ',F5.1,'      ',F5.2,'      ',F5.2,'      ',F5.2)
      ENCODE(96,500,ILA1)
500 FORMAT('                                POSITION')
      CALL TEXT8(1,ILA1,24,3,1,1,3,IER)
      IF (IER.NE.0) OUTPUT(101) IER, '      POSITION'
      ENCODE(96,502,ILA2)
502 FORMAT('                                X          Y          ZZ          PSI
CPHI          THETA')
      CALL TEXT8(1,ILA2,24,4,1,1,3,IER)
      ENCODE(96,505,ILA3)
505 FORMAT('                                VELOCITY')

```

```

105:      CALL TEXT8(1,ILA3,24,11,1,1,3,IER)
106:      IF(IER.NE.0)OUTPUT(101) IER, '    VELOCITY'
107:      ENCODE(96,517,ILA4)
108: 517 FORMAT('          U          V          W          R
109:      CP          G')
110:      CALL TEXT8(1,ILA4,24,12,1,1,3,IER)
111:      IF(IER.NE.0)OUTPUT(101) IER, '    LIST VAR VELOCITY'
112:      ENCODE(96,509,ILA5)
113: 509 FORMAT('          ACCELERATION')
114:      CALL TEXT8(1,ILA5,24,19,1,1,3,IER)
115:      IF(IER.NE.0)OUTPUT(101) IER, '    ACCEL TITLE'
116:      ENCODE(96,512,ILA6)
117: 512 FORMAT('          QDST          VDST          WDST          RDST
118:      CST          QDST')
119:      CALL TEXT8(1,ILA6,24,20,1,1,3,IER)
120:      IF(IER.NE.0)OUTPUT(101) IER, '    ACCEL VAR'
121:      ENCODE(96,514,ILA7)
122: 514 FORMAT(' CONTROL INPUTS          TIME
123:      CIGATION DATA')
124:      CALL TEXT8(1,ILA7,24,27,1,1,3,IER)
125:      IF(IER.NE.0)OUTPUT(101) IER, '    CONTROL HEADING'
126:      ENCODE(96,515,ILA8)
127: 515 FORMAT('THRUST    RUDDER    DELT    ELAPSED    PITCH    HEADING
128:      CATE    DRIFT    ROLL    SPEED')
129:      CALL TEXT8(1,ILA8,24,28,1,1,3,IER)
130:      IF(IER.NE.0)OUTPUT(101) IER, '    SUB LABEL CONTROL'
131:      CALL WRITECLOCK(0)
132:      CALL STARTCLOCK
133: 101 CONTINUE
134:      CALL ADDA(AD,NAD,AA,NDA)
135:      CALL READCLOCK(N)
136:      CALL WRITECLOCK(0)
137:      X1=PSI/6.283185
138:      IX=X1
139:      AIX=X1-IX
140:      IF(AIX.LT.0.0)G9 T9 10
141:      HEAD=AIX*360.
142:      G9 T9 11
143: 10  AIX1=1.+AIX
144:      HEAD=AIX1*360.
145: 11  CONTINUE
146:      ARATE=(360.*R)/6.283185
147:      AR9LL=(360.*PHI)/6.283185
148:      APITCH=(360.*THETA)/6.283185
149:      SPEED=U*.597213
150:      IF(H1.GT.X0)G9 T9 700
151:      H1=X0
152: 700 IF(H2.GT.Y0)G9 T9 701
153:      H2=Y0
154: 701 IF(H3.GT.ZZ)G9 T9 702
155:      H3=ZZ
156: 702 IF(H4.GT.PSI)G9 T9 703
157:      H4=PSI

```

703 IF(H5.GT.PHI)G9 T9 704
H5=PHI
704 IF(H6.GT.THETA)G9 T9 705
H6=THETA
705 IF(H7.GT.U)G9 T9 706
H7=U
706 IF(H8.GT.V)G9 T9 707
H8=V
707 IF(H9.GT.W)G9 T9 708
H9=W
708 IF(H10.GT.R)G9 T9 709
H10=R
709 IF(H11.GT.P)G9 T9 710
H11=P
710 IF(H12.GT.Q)G9 T9 711
H12=Q
711 IF(H13.GT.UDET)G9 T9 712
H13=UDET
712 IF(H14.GT.VDET)G9 T9 713
H14=VDET
713 IF(H15.GT.WDET)G9 T9 714
H15=WDET
714 IF(H16.GT.RDET)G9 T9 715
H16=RDET
715 IF(H17.GT.PDET)G9 T9 716
H17=PDET
716 IF(H18.GT.QDET)G9 T9 718
H18=QDET
718 IF(H30.LT.X0)G9 T9 719
H30=X0
719 IF(H31.LT.Y0)G9 T9 720
H31=Y0
720 IF(H32.LT.ZZ)G9 T9 721
H32=ZZ
721 IF(H33.LT.PSI)G9 T9 722
H33=PSI
722 IF(H34.LT.PHI)G9 T9 723
H34=PHI
723 IF(H35.LT.THETA)G9 T9 724
H35=THETA
724 IF(H36.LT.U)G9 T9 725
H36=U
725 IF(H37.LT.V)G9 T9 726
H37=V
726 IF(H38.LT.W)G9 T9 727
H38=W
727 IF(H39.LT.R)G9 T9 728
H39=R
728 IF(H40.LT.P)G9 T9 729
H40=P
729 IF(H41.LT.Q)G9 T9 730
H41=Q
730 IF(H42.LT.UDET)G9 T9 731

```

211:      H42=UDBT
212: 731 IF(H43.LT.VDBT)GO TO 732
213:      H43=VDBT
214: 732 IF(H44.LT.WDBT)GO TO 733
215:      H44=WDBT
216: 733 IF(H45.LT.RDBT)GO TO 734
217:      H45=RDBT
218: 734 IF(H46.LT.PDBT)GO TO 735
219:      H46=PDBT
220: 735 IF(H47.LT.GDBT)GO TO 736
221:      H47=GDBT
222: 736 CONTINUE
223:      DELT=(DELT+(N/60.))/2.
224:      TIME=TIME+DELT
225: 651 Z=-0.5+A91
226:      IF(Z.GT..5)GO TO 790
227:      IF(Z.LT.-.5)GO TO 791
228:      IF(Z.GT..005)GO TO 792
229:      IF(Z.LT.-.005)GO TO 792
230:      Z=0.0
231:      GO TO 792
232: 790 Z=.5
233:      GO TO 792
234: 791 Z=-.5
235:      GO TO 792
236: 792 CONTINUE
237:      T=AT*A81*100.
238:      IF(T.GT.375.)GO TO 793
239:      IF(T.LT.0.0)GO TO 794
240:      GO TO 795
241: 793 T=375.
242:      GO TO 795
243: 794 T=0.0
244:      GO TO 795
245: 795 CONTINUE
246: 998 CONTINUE
247:      PAAP=00.20*SIN(PSI)
248:      PHI=R
249:      THETA=UDBT
250:      W=PAAP
251:      P=PAAP
252:      Q=PAAP
253:      WDBT=PAAP
254:      PDBT=PAAP
255:      GDBT=PAAP
256:      U=A11*X*AU
257:      V=A21*X*AV
258:      R=A31*X*AR
259:      UDBT=(((-1.)*(CDX/180.)*U+J)+((T/180.)*COS(Z))+V*R
260:      VDBT=((T/M)*SIN(Z))-((CDY/M)*V*ABS(V))-J*R
261:      RDBT=((CDY/IZ)*LX*V*ABS(V))-((T/IZ)*L9*SIN(Z))+A22*J*V*(LX/IZ))
262:      BETA=ATAN(V/U)
263:      VS=((U*U)+(V*V))**.5

```

```

PSI=PSI+DELT*R
XODBT=U*C8S(PSI)-V*SIN(PSI)
YODBT=U*SIN(PSI)+V*C8S(PSI)
XO=XO+DELT*XODBT
YO=YO+DELT*YODBT
B11=UDBT/(AUDBT*100.)
B21=VDBT/(AVDBT*100.)
B31=RCBT/(ARDBT*100.)
B71=XO/(AXO*100.)
B81=YO/(AYO*100.)
IF(SENSE SWITCH 1)102,105
102 CALL HOLD
CALL STOPCLOCK
WRITE(6,100)LR,JD,TTD,TD,TBEP,HEAD,ATVECD,CCC,TVEC
100 FORMAT(9F9.4)
CALL STARTCLOCK
CALL COMPUTE
105 CONTINUE
IF(A101.GT.-0.5)G9 T9 101
IC9=IC9+1
IF(IC9.EQ.1)G9 T9 653
IF(IC9.EQ.3)G9 T9 653
IF(IC9.EQ.15)G9 T9 653
IF(IC9.EQ.22)G9 T9 653
IF(IC9.EQ.29)G9 T9 653
IF(IC9.EQ.36)G9 T9 653
G9 T9 107
653 ENCODE(26,501,ILAP)YO,XO,ZZ,PSI,PHI,THETA
600 CALL TEXT9(1,ILAP,24,6,1,1,3,IER)
IF(IER.NE.0)OUTPUT(101) IER, ' PRESENT'
107 IF(IC9.EQ.5)G9 T9 108
G9 T9 109
108 ENCODE(96,525,ILAP)42,41,43,44,45,46
CALL TEXT9(1,ILAP,24,8,1,1,3,IER)
109 IF(IC9.EQ.10)G9 T9 110
G9 T9 111
110 ENCODE(96,526,ILAP)431,430,432,433,434,435
CALL TEXT9(1,ILAP,24,9,1,1,3,IER)
111 IF(IC9.EQ.2)G9 T9 601
IF(IC9.EQ.9)G9 T9 601
IF(IC9.EQ.16)G9 T9 601
IF(IC9.EQ.23)G9 T9 601
IF(IC9.EQ.30)G9 T9 601
IF(IC9.EQ.37)G9 T9 601
G9 T9 112
601 ENCODE(96,507,ILAP)U,V,W,R,P,Q
CALL TEXT9(1,ILAP,24,14,1,1,3,IER)
112 IF(IC9.EQ.15)G9 T9 113
G9 T9 114
113 ENCODE(96,527,ILAP)47,48,49,410,411,412
CALL TEXT9(1,ILAP,24,16,1,1,3,IER)
114 IF(IC9.EQ.20)G9 T9 115
G9 T9 116

```

```

317: 115 ENCODE(96,528,ILAP)H36,H37,H38,H39,H40,H41
318: CALL TEXT8(1,ILAP,24,17,1,1,3,IER)
319: 116 IF(IC8.EQ.3)G8 T8 604
320: IF(IC8.EQ.10)G8 T8 604
321: IF(IC8.EQ.17)G8 T8 604
322: IF(IC8.EQ.24)G8 T8 604
323: IF(IC8.EQ.31)G8 T8 604
324: IF(IC8.EQ.38)G8 T8 604
325: G8 T8 117
326: 604 ENCODE(96,511,ILAP)UD8T,VD8T,WD8T,RD8T,PD8T,QD8T
327: CALL TEXT8(1,ILAP,24,22,1,1,3,IER)
328: 117 IF(IC8.EQ.25)G8 T8 118
329: G8 T8 119
330: 118 ENCODE(96,529,ILAP)H13,H14,H15,H16,H17,H18
331: CALL TEXT8(1,ILAP,24,24,1,1,3,IER)
332: 119 IF(IC8.EQ.30)G8 T8 120
333: G8 T8 121
334: 120 ENCODE(96,530,ILAP)H42,H43,H44,H45,H46,H47
335: CALL TEXT8(1,ILAP,24,25,1,1,3,IER)
336: 121 IF(IC8.EQ.4)G8 T8 602
337: IF(IC8.EQ.11)G8 T8 602
338: IF(IC8.EQ.18)G8 T8 602
339: IF(IC8.EQ.25)G8 T8 602
340: IF(IC8.EQ.32)G8 T8 602
341: IF(IC8.EQ.39)G8 T8 602
342: G8 T8 923
343: 602 ENCODE(96,516,ILAP)T,Z,DELT,TIME,APITCH,HEAD,ARATE,BETA,AROLL,SPEED
344: CD
345: CALL TEXT8(1,ILAP,24,30,1,1,3,IER)
346: 923 IF(A101.GT.-0.90)G8 T8 924
347: U=0.
348: V=0.
349: W=0.
350: R=0.
351: P=0.
352: Q=0.
353: XO=0.
354: YO=0.
355: ZZ=0.
356: PSI=0.
357: PHI=0.
358: THETA=0.
359: UD8T=0.
360: VD8T=0.
361: WD8T=0.
362: RD8T=0.
363: PD8T=0.
364: QD8T=0.
365: TIME=0.
366: H1=0.
367: H2=0.
368: H3=0.
369: H4=0.

```

```

H5=0.
H6=0.
H7=0.
H8=0.
H9=0.
H10=0.
H11=0.
H12=0.
H13=0.
H14=0.
H15=0.
H16=0.
H17=0.
H18=0.
H30=0.
H31=0.
H32=0.
H33=0.
H34=0.
H35=0.
H36=0.
H37=0.
H38=0.
H39=0.
H40=0.
H41=0.
H42=0.
H43=0.
H44=0.
H45=0.
H46=0.
H47=0.
924 CONTINUE
IF(ICB.EQ.5)G8 T9 603
IF(ICB.EQ.12)G8 T9 603
IF(ICB.EQ.19)G8 T9 603
IF(ICB.EQ.26)G8 T9 603
IF(ICB.EQ.33)G8 T9 603
IF(ICB.EQ.40)G8 T9 603
G8 T9 610
603 CONTINUE
58 CONTINUE
X1X=.45*C8S(PH1)
Y1Y=.45*SIN(PH1)
X1XA=(2.5*R)+X1X
X11=2.5*R
Y1YA=THETA-Y1Y
X1XB=(2.5*R)-X1X
Y1YB=THETA+Y1Y
X1XC=(2.5*R)+(0.1*SIN(PH1))
Y1YC=THETA+(0.1*C8S(PH1))
IC8A=IC8A+1+(1.*U)+(10.*(IC8A/514.))
Y1YD=(IC8A/514.)*(-1.0)+(THETA)-0.1+

```

```

423:      Y1YE=(IC9A/514.)*(-1.0)+(THETA)-0.14
424:      X1XD=(X1XB-0.05)-((IC9A/514.)*0.2)
425:      X1XE=X1XB-0.05
426:      X1XF=X1XA+0.05
427:      X1XG=(X1XA+0.05)+((IC9A/514.)*0.2)
428:      Y1YR=Y1YA-0.14
429:      Y1YL=Y1YB-0.14
430:      H=(0.2/COS(PHI))
431:      H1=H*SIN(PHI)
432:      Y1YEE=Y1YE-(IC9A/2700.)
433:      REARA1=-0.5
434:      REARA2=-0.5+Y1Y
435:      REARB1=-0.5
436:      REARB2=-0.6++Y1Y
437:      REARC1=0.5
438:      REARC2=-0.5-Y1Y
439:      REARD1=0.5
440:      REARD2=-0.6+-Y1Y
441: 65  SESX=0.75+(YC/5000.)
442:      SESY=0.75+(XC/5000.)
443:      IF(Y1YE.GT.-0.6)G9 T9 59
444:      IC9A=0
445: 59  CONTINUE
446:      IVIEWA(1)=IHEAD(0,10)
447:      IVIEWA(2)=IPACK(REARA1,REARA2,0)
448:      IVIEWA(3)=IPACK(X1XB,Y1YB,1)
449:      IVIEWA(4)=IPACK(X1XA,Y1YA,1)
450:      IVIEWA(5)=IPACK(REARC1,REARC2,1)
451:      IVIEWA(6)=IPACK(REARA1,REARA2,1)
452:      IVIEWA(7)=IPACK(REARB1,REARB2,1)
453:      IVIEWA(8)=IPACK(REARD1,REARD2,1)
454:      IVIEWA(9)=IPACK(REARC1,REARC2,1)
455:      IF(R.GT..02)G9 T9 50
456:      IF(R.LT.--02)G9 T9 51
457:      IVIEWA(10)=IPACK(X1XD,Y1YEE,0)
458:      IVIEWA(11)=IPACK(X1XE,Y1YE,1)
459:      IVIEWA(12)=IPACK(X1XF,Y1YE,0)
460:      IVIEWA(13)=IPACK(X1XG,Y1YEE,1)
461:      IVIEWA(14)=IPACK(0.0,0.0,0)
462:      G9 T9 55
463: 50  IVIEWA(10)=IPACK(X1XA,Y1YA,0)
464:      IVIEWA(11)=IPACK(X1XA,Y1YR,1)
465:      IVIEWA(12)=IPACK(REARD1,REARD2,1)
466:      IVIEWA(13)=IPACK(X1XF,Y1YE,0)
467:      IVIEWA(14)=IPACK(X1XG,Y1YEE,1)
468:      G9 T9 55
469: 51  IVIEWA(10)=IPACK(X1XB,Y1YB,0)
470:      IVIEWA(11)=IPACK(X1XB,Y1YL,1)
471:      IVIEWA(12)=IPACK(REARB1,REARB2,1)
472:      IVIEWA(13)=IPACK(X1XE,Y1YE,0)
473:      IVIEWA(14)=IPACK(X1XD,Y1YEE,1)
474:      G9 T9 55
475: 55  CONTINUE

```

DATE

```
IVIEWA(15)=IPACK(SESX,SESY,0)
IVIFVA(16)=IPACK(SESX,SESY,1)
IVIEWA(17)=0
CALL GRAPH0(2,IVIEWA,17,2,IER)
610 IF(IC0.LE.40)GO TO 101
IC0=0
GO TO 101
END
```

INITIAL DISTRIBUTION LIST

	Copies
1. Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2. Commander, Naval Sea Systems Command Surface Effects Ships Project Office PMS-304-31 P.O. Box 34401 Bethesda, Maryland 20034	6
3. Library, Code 0142 Naval Postgraduate School Monterey, California 93940	2
4. Office of Research Administration Code 012A Naval Postgraduate School Monterey, California 93940	1
5. Professor A. Gerba, Jr., Code 62Gz Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	6
6. Professor G. J. Thaler, Code 62Tr Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	5

U188771

Naval Postgraduate School.
NPS-62-79-008.

27 MAR 91

36781

U188771

DUDLEY KNOX LIBRARY - RESEARCH REPORTS



5 6853 01062497 6

U18877